## Investigation of the Influence of Microgravity on Transport Mechanisms in a Virtual Spaceflight Chamber - A Ground-Based Program

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## **Background and Introduction**

In January 1992, the First International Microgravity Laboratory's (IML-1) Fluids Experiment System (FES) experiment produced a set of classic experimental data and a 40 hour holographic "movie" of an ensemble of spheres in a fluid in microgravity. Because the data are in the form of holograms, we can study the three-dimensional distribution of particles with unprecedented detail by a variety of methods and for a wide variety of interests. The possession of the holographic movie is tantamount to having a complex experiment in space while working in an easily accessible laboratory on earth. The movie contains a vast amount of useful data, including residual g, g-jitter, convection and transport data, and particle fluid interaction data. The information content in the movie is so great that we have scarcely begun to tap into the data that is actually available in the more than 1,000 holograms, each containing as much as 1,000 megabytes of information. This ground-based project is exploiting this data and the concept of holographic storage of spaceflight data to provide an understanding of the effects of microgravity in materials processing. This paper provides the foundation, objectives, and status of the ground-based project.

The types of information extractable from these holograms can improve our understanding of the microgravity environment, thereby allowing NASA to better exploit its use in such applications as crystal growth from solution. The early part of this investigation has made use of existing holographic data produced in the IML-1 experiment to advance the understanding of convection in the Space Shuttle environment, g-jitter effects on crystal growth, and complex transport phenomena in low Reynolds number flows.

## **Objectives**

The primary objective of this project is to advance the understanding of microgravity effects on crystal growth, convection in materials processing in the space environment, and complex transport phenomena at low Reynolds numbers. This objective is being achieved both experimentally and theoretically. Experiments are making use of existing holographic data recorded during the IML-1 spaceflight. A parallel theoretical effort is providing the models for understanding the particle fields and their physics in the microgravity environment.

## Discussion

In a microgravity environment, particles of different size and density can be studied side-by -side, since the settling rate is extremely low. Those that are denser than the fluid will move in the direction of the residual gravity, while those that are less dense move against the direction of residual gravity. Neutrally buoyant particles move only if the fluid itself moves. The particles actually cause micro-convection in the fluid. At the extremely low Reynolds numbers of these studies, a particle influences its environment out to at least 10 particle diameters. Consequently, the data interpretation requires accounting for the immediate environment of the particle. For fluid velocimetry, particles with no nearby neighbors must be used. A neutrally buoyant particle that might otherwise remain motionless may move under the influence of a nearby heavier or lighter particle.

Drs. Rangel and Coimbra, using fractional derivative techniques, have discovered a new, analytical solution to the equation of motion of a particle in a fluid under conditions that are especially of interest in a microgravity environment. They applied the work to specific cases of interest for this program and have provided data to support potential flight experiments. The paper will discuss some of the preliminary results.

One of the first tasks was to build a database of three dimensional particle positions in each of the holograms (or different time elements). For particle image tracking, the real image of the cell is reconstructed into the field of a microscope to which a television camera is attached. The microscope is programmed to move through the 3-D image, stopping to grab frames at predetermined positions. Afterwards, all images are analyzed to find for each particle where it reaches its best focus and the X-, Y- and Z-position is determined. With this database, searching for specific particles (like particles with no neighbors or particles near of the wall) becomes easy. Having the data in this form has allowed us to devise a range of measurement techniques that extend the dynamic range and accuracy of the measurement. One method for extending the spatial resolution is to employ more than one particle size to reduce confusion between different tracer particles. By using several different particle sizes, we improved the spatial resolution as well as the dynamic range of the velocity measurement since the terminal velocity is proportional to the square of the particle diameter, the particle/fluid density ratio, and the acceleration, g. Each factor of two in particle size quadruples the measurable velocity range. In future experiments, particle size can also be used to distinguish different particle materials.

A self-correcting method for measuring effects of g and g-jitter without actually determining velocity of an individual particle is to measure the relative velocity between two different particle sizes. The separation of small and large particles located close to each other is proportional to the gravity force and is not affected by registration or by convection. This is a unique way to separate the observance of convection and gravity. This procedure has been the most accurate way to measure residual gravity and g-jitter, since the process cancels the effects of convection and minimizes registration errors, and the particle tracks provide a direct measure of residual g. Gravitational effects in crystallization, such as steady and fluctuating (jitter) components of the g-field, are important factors to be considered when lengthy crystal growth experiments in space are performed. These are the parameters that we can measure with the IML-1 data and with the concepts under investigation.